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TEACHING OF INTONATION AND INFLECTIONS TO THE DEAF.
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RESEARCH WAS CONDUCTED IN THE DEVELOPMENT AND TESTING OF A SELF-MONITORING METHOD OF TEACHING PROPER INTONATION AND INFLECTION PATTERNS TO THE DEAF. THIS TEACHING METHOD INCLUDED USE OF A VISUAL DISPLAY WHICH IS BASED ON PITCH INFORMATION DERIVED FROM A LIVE SPEECH SIGNAL. FOUR PROFOUNDLY DEAF CHILDREN WERE THE SUBJECTS FOR THE EXPERIMENT. A SPEECH EXTRACTOR (OSCILLOGRAPH) WAS USED TO VISUALLY DISPLAY VOICE SOUNDS PRODUCED BY THE INSTRUCTOR AND SUBJECTS. INSTRUCTION IN VOWEL SOUNDS WAS AIDED BY HAVING EACH SUBJECT TOUCH THE INSTRUCTOR'S THROAT WHILE AT THE SAME TIME TOUCHING HIS OWN. IN ADDITION, DIAPHRAGMATIC BREATHING AND BETTER SITTING POSTURE WERE INTRODUCED. SOME OF THE CONCLUSIONS REACHED WERE--(1) THE CONCEPT OF TEACHING PITCH VARIATION OR PITCH INFLECTION TO DEAF INDIVIDUALS USING A SELF-MONITORING DEVICE SUCH AS THE PITCH EXTRACTOR IS POSSIBLE. (2) VOLUME AND DURATION ARE THE MOST SIGNIFICANT FACTORS IN THE PRODUCTION OF THE VISUAL DISPLAY, (3) KNOWLEDGE OF THE SUBJECT APPEARS TO BE IMPORTANT FOR SUCCESSFUL PERFORMANCE, AND (4) ATTENTION AND INTEREST SPANS ARE IMPORTANT VARIABLES TO BE CONSIDERED IN THE TEACHING PROCESS. FURTHER RESEARCH WAS RECOMMENDED WITH RESPECT TO INCREASING THE NUMBER OF LESSONS, USING DEAF CHILDREN WITH ABOVE AVERAGE IQ, AND PERFECTING THE EQUIPMENT AND TECHNIQUES. (AW)

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Cooperative Research Project No. S-281

Ladislav Dolansky, Chief Investigator
Robert J. Ferullo
Maureen C. O'Donnell
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TABLE OF CONTENTS

	Page
RESEARCH PERSONNEL	i
ACKNOWLEDGMENT	ii
TABLE OF CONTENTS	iii
LIST OF ILLUSTRATIONS	v
I. INTRODUCTION	1
II. THE PROBLEM	1
III. OBJECTIVES	1
IV. RELATED RESEARCH	1
V. PROCEDURES	4
A. Pre-instructional experimentation	5
B. Pre-instructional rapport with deaf subjects	5
C. Final experimental session	5
D. Trial session with deaf subject	6
E. Instructional lesson 1	6
F. Instructional lesson 2	6
G. Pre-instructional training	6
H. Instructional lesson 3	7
I. Instructional lesson 4	7
VI. EXPERIMENTAL DATA AND FINDINGS	7
VII. ANALYSES OF THE DATA AND FINDINGS	8
A. Subject A	8
1. Instructional lesson 1	8
2. Instructional lesson 2	8
3. Instructional lesson 3	8
4. Instructional lesson 4	9
B. Subject B	9
1. Instructional lesson 1	9
2. Instructional lesson 2	9
3. Instructional lesson 3	9
4. Instructional lesson 4	10
C. Subject C	10
1. Instructional lesson 1	10
2. Instructional lesson 2	10
3. Instructional lesson 3	10
4. Instructional lesson 4	10

D. Post-instructional testing 11
E. Comparison of pre-instructional and post-instructional imitations 11

VIII. CONCLUSIONS AND IMPLICATIONS 12

IX. LIMITATIONS 15

X. SUGGESTIONS FOR FURTHER RESEARCH 15

XI. REFERENCES 16

APPENDIX A - PITCH-EXTRACTION EQUIPMENT AND LISTENING FACILITIES 17
1. Introduction 17
2. Pitch-extraction and display equipment 17
3. Equipment modifications and additions 17
a. Pitch-period indicator 17
b. Saw-tooth generator 20
c. Inverter and peak detector 20
d. Divider 22
e. Visual display 22
4. Equipment performance 22
5. Listening room 24
6. Concluding remarks 24

References 25

APPENDIX B - SUBJECT DATA SHEET FOR YOUNG ADULT 26

APPENDIX C - SUBJECT DATA SHEET FOR SUBJECT A 27

APPENDIX D - SUBJECT DATA SHEET FOR SUBJECT B 28

APPENDIX E - SUBJECT DATA SHEET FOR SUBJECT C 29

APPENDIX F - HEARING EVALUATIONS OF SUBJECTS 30

APPENDIX G - OSCILLOGRAPHIC PITCH PATTERNS 31

APPENDIX H - INSTRUCTIONS FOR RATING OF IMITATION 32

LIST OF ILLUSTRATIONS

		Page
Fig. 1.	Pitch patterns produced by saying the words "good morning" in two different ways. Accented syllables are underlined. (From ref. 1)	2
Fig. 2.	Pitch patterns produced by saying the words "who are you" in two different ways. Accented syllables are underlined. (From ref. 1)	2
Fig. 3.	Speech waveform (a) and the corresponding trapezoidal (constant-slope) waveform (b).	3
Fig. 4.	Display resulting from horizontally compressing the display of Fig. 3. The lower edge of (b) represents the pitch frequency vs. time.	3
Fig. 5.	Subject A; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.	12
Fig. 6.	Subject B; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.	13
Fig. 7.	Subject C; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.	14
Fig. A1.	Waveforms for the word "choice" at various points of the pitch extracting equipment, (a) speech-signal input e_s, (b) saw-tooth generator output e_{so}, (c) detector output e_{io}, (d) divider output e_{do}, (e) gate control signal e_{gc}, (f) pitch frequency (f_p) vs. time (t) display on oscilloscope. (Time scale expanded with respect to normal use.)	18
Fig. A2.	Pitch-extractor and display equipment. The waveforms at the points identified by the letters a, b, c, etc. are shown in Fig. A1.	19
Fig. A3.	Saw-tooth generator.	20
Fig. A4.	Inverter and peak detector.	20
Fig. A5.	Voiced-unvoiced indicator and gating circuit.	21
Fig. A6.	Vertical deflection voltage e_{dv} vs. pitch frequency f_{in}.	22
Fig. A7.	Examples of waveforms obtained at points a, b, e, f (See Fig. A1 and A2) in actual operation.	23
Fig. F1.	Audiograms for Deaf Subjects; o right-ear response, X left-ear response, ↓ no response, right ear, ↓ no response, left ear.	30
Fig. G1.	Examples of pattern-imitation efforts of Subject B.	31

I. INTRODUCTION

The education of deaf children, the teaching of speech with respect to intonation and the inflections presents a great problem. In the absence of acoustical feedback to indicate any deviation from the proper inflectional pattern, a deaf person is deprived of an indicator for corrections of his speech and voice, and pitch remains a very abstract concept to the deaf. The resulting speech patterns of deaf persons frequently exhibit nonacceptable forms of speech which tend to impede the personal adjustment of such persons.

II. THE PROBLEM

The research reported in this document is addressed to the problem of developing and testing a self-monitoring method of teaching proper intonation and inflection patterns to the deaf, particularly deaf children, by means of a visual display which is based on pitch information derived from a live speech signal.

III. OBJECTIVES

The research effort described in this report was concerned with the following main objectives:

1. To test the hypothesis that the pitch and/or rhythmic patterns of the speech produced by profoundly deaf subjects, particularly school children, can be modified by means of a pitch intonation teaching method, based on the use of a pitch extractor[2]. The latter extracts from the live speech signal pertinent information for an oscillographic display of the pitch* versus time.

2. To further develop, modify and adjust existing pitch-extraction equipment[2], as needed, so as to meet the requirements of objective (1). Such developments include improvements and modifications of the original pitch-extraction equipment as well as new means of displaying the extracted information in a form suitable for use by deaf individuals, in a self-monitoring way.

3. To test the hypothesis that the visual display is useful as a self-monitoring device in teaching proper intonation and inflection patterns to profoundly deaf children.

4. To gather empirical data during instructional lessons with profoundly deaf children, in order to learn some of the factors which may or may not be significantly related to the teaching and learning process.

IV. RELATED RESEARCH

Not many reports on the use of visible speech displays for speech improvement and speech therapy are found in the literature. At the Detroit School for the Deaf, Kopp[4] is using visual displays of formant structures of sounds, words, and phrases in teaching speech to deaf children in the intermediate grades.

Pronovost[7] has reported on a pilot study conducted at the Boston School for the

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*In this report pitch means the fundamental frequency of the voice.

Deaf. In this study, a voice visualizer developed by Dr. Robert Lerner of the Massachusetts Institute of Technology was used. Pronovost's study involved twelve deaf children, ranging in age from 7 years to 16 years. Tape recordings were made of a word articulation test before and after instructional periods. Tape recording analyses indicated that most children could produce normal vowel quality during the instructional lessons, but did not maintain this quality in the second word-articulation test. The most salient improvement was in the articulation of fricative sounds, both voiced and unvoiced.

In England, at the Whitebrook School for the Deaf, Searson[8] used the Kamplex Visible Speech Apparatus to study ten children between the ages of 3 years, 11 months and 11 years, 1 month. These children had severe to profound hearing losses. Each child had daily speech lessons of from 10 to 15 minutes; eight of the children had 25 to 28 lessons, one had 21, and one had 19. It was concluded that the Kamplex machine proved extremely helpful in teaching the deaf children the proper articulation of consonants, particularly fricatives; but it was not so useful in showing the differences between vowel sounds. Also, it has helped to monitor voice pitch and improve voice quality.

In his paper published in 1960, F. Anderson[1] described a method of visual display of pitch information for the deaf. Figs. 1 and 2 indicate how the fundamental frequency of the human voice is represented vertically while time is represented on the horizontal axis. As reported by Anderson, this display was convenient (a) for the transmission of the temporal information to the deaf, and (b) for the transmission of pitch and inflection information to the deaf.

Fig. 1 Pitch patterns produced by saying the words "good morning" in two different ways. Accented syllables are underlined. (From ref. 1)

Fig. 2 Pitch patterns produced by saying the words "who are you" in two different ways. Accented syllables are underlined. (From ref. 1)

Anderson found that, of the two, the first was more easily assimilated by the subject, and represented a natural stepping stone to the more abstract assimilation of pitch information.

As indicated in Anderson's paper[1], his device was based on the "pitch period indicator," originally developed by the project director of the present research[2]. Therefore, the present research effort was based on the pitch-period indicator avail-

able at Northeastern University, with certain modifications and additions as described later in this report. The principle of operation of the instantaneous pitch-period indicator is best explained by means of Figs. 3 and 4. In Fig. 3(a) the waveform for a voiced speech sound, showing the typical periodicity of such sounds, is presented. For

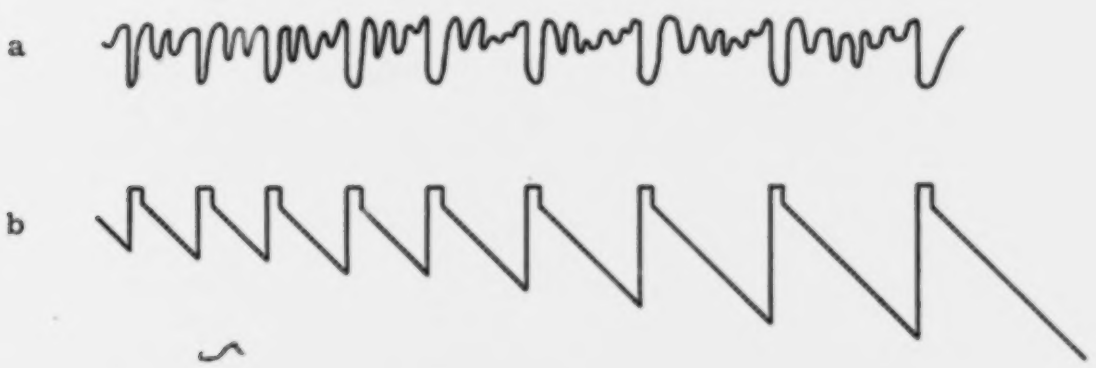

Fig. 3. Speech waveform (a) and the corresponding trapezoidal (constant-slope) waveform (b).

Fig. 4. Display resulting from horizontally compressing the display of Fig. 3. The lower edge of (b) represents the pitch frequency vs. time.

each period of this waveform, the indicator generates a pulse which may be used to generate the waveform shown in Fig. 3(b)*. A higher fundamental frequency corresponds to a closer spacing of the repeated waveform trains of the original waveform and therefore to more closely spaced trapezoidal waveforms in Fig. 3(b). However, the latter have always the same slope so that for a higher fundamental frequency, the terminating point of the slope remains at a higher level than for a lower fundamental frequency. If the waveforms of Fig. 3 are compressed in time, patterns such as the ones shown in Fig. 4 result. The lower edge of the waveforms in Fig. 4(b) represents the fundamental pitch frequency vs. time. Certain modifications of the display with respect to linearity in time or frequency, suppression of unvoiced portions of the speech signal, etc. became desirable in the course of the research. These considerations and the associated modifications are treated in more detail in Appendix A.

As a result of his research, Anderson reported a certain amount of success in

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*The trapezoidal waveform shown in Fig. 3(b) was later modified to a triangular wavefrom.

the problem of teaching rhythm and intonation and also indicated the desirability of additional work in this direction[2]. It is important to observe that this method is self-monitoring inasmuch as the subject can visually compare the patterns generated by his voice to an earlier pattern produced by the teacher; in varying his pronunciation, he can establish for himself whether his attempt to vary the fundamental voice frequency is bringing his pattern into closer agreement to the one produced by the teacher, or not.

A method of obtaining the pitch signal with the help of a throat microphone was recently described by P. Tjernlund[10]. This method is based on earlier work by Sugimoto and Hiki[9], and Porter[5]. It is claimed that these techniques allow an extraction of pitch pulses comparatively free from the influence of articulation, and that the effective S/N ratio is at least 20 dB better than when oral waves are used. Time did not permit to incorporate this feature into our experiment; however, much more error-free operation of pitch extraction circuit could be expected with this method since the waveform obtained by the throat microphone is of much simpler shape than the oral-pickup waveform. A slight disadvantage of the method would be the fact that the microphone must be attached to the throat of the subject. In spite of this disadvantage, it is believed that this method should definitely be tried in the future.

V. PROCEDURES

For the first portion of this pilot study, a profoundly deaf high school sophomore male with a chronological age of 17 years, 10 months and an Intelligence Quotient (IQ) of 103 on the Wechsler Adult Intelligence Scale (WATS) was selected for a trial session, to determine the psychoeducational and technical procedures, and the related variables that may influence the teaching and learning process with later, much younger subjects. *

Following the trial lesson, each of three profoundly deaf children, ** who were attending the Boston School for the Deaf, was given one twenty-minute instructional lesson per week at Northeastern University, for four weeks.

The speech pathologist who served as the teacher on this project made weekly visits to the Boston School for the Deaf to establish rapport with the children, and to work with them using the voice visualizer[7] and a VU meter.

A listening studio with an adjacent engineering control room was used for the testing. A graduate student engineer was present during each lesson.

Pre-instructional and post-instructional testing was done with each child. Simple isolated vowel sounds were used as the speech signal.

Each child was received in the testing studio by a qualified psychologist and speech pathologist who spent some time on establishing rapport and on presenting the subjects with a general orientation as to the structure of the planned experiment. Specific procedures used in this pilot study varied from instructional lesson to instruc-

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* For additional data about this subject, see Appendix B.

** Biographical data for these children are given in Appendices C, D, and E.

tional lesson. The variations in the procedures were necessary because of the empirical data gleaned during each preceding session. The specific procedures followed throughout this pilot study were as follows:

A. Pre-instructional experimentation.

During the first two weeks the speech and hearing therapist and the speech pathologist devoted more of their time to experimentation with the pitch extractor in the studio located on the Northeastern University campus. The purposes of this pre-instruction experimentation were: (1) to familiarize the teaching staff of the study with the pitch extractor, (2) to work with the engineer in working out the necessary equipment modifications and adjustments. Although the teaching staff members did not actually make equipment modifications themselves; it was imperative that they learn about certain controls of the pitch extractor and of the visual display. They also helped to formulate certain essential modifications, e.g. with respect to the visual display which the engineer, if necessary with the aid of the project director, could then implement. The pathologist accompanied the therapist during all pre-instruction and instruction sessions.

B. Pre-instructional rapport with deaf subjects.

Frequent visits were made to the Boston School for the Deaf. It was felt that such visits would: (1) provide them and the deaf children with opportunities to establish rapport, to facilitate the efficacy of the teaching and learning experiences in the studio on the campus; (2) aid the children in understanding the concept of duration and volume; and (3) aid the teacher in discerning which vowels the children could make easily.

While at the Boston School for the Deaf, each child was seen individually by the teacher for periods of approximately thirty minutes each. The voice visualizer was used to learn something about the ranges and levels of the children's pitch and the sounds which were most easily produced by them. In addition, these experiences were used to practice the utilization of a visual stimulus for monitoring the duration of sounds produced by the deaf children. Sounds used during the practice sessions were:* [ɑ] (a(r)), [i] (ee), [oU] (o-e), [ɛ] (e), [u] (o͞o), [m] (m), [s] (s), [z] (z), and [f] (f).

While at the Boston School for the Deaf the staff established through experimental teacning that the deaf children to be used as subjects in this pilot study could not grasp the concept of pitch variation or the "up" and "down" concept.

C. Final experimental session.

The engineer, the pathologist, and the therapist took part in a final experimental session with the equipment. Tape recordings of the therapist's and pathologist's voice signals were made and the pitch patterns derived from them were displayed visually. These were used to make further technical adjustments. It was now determined that the equipment, the pathologist, and the therapist were ready to experiment with a deaf subject.

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* Throughout this report, the speech sounds are identified both in terms of the international phonetic alphabet and the Northampton vowel chart, e.g. [ɑ] (a(r)).

D. Trial session with deaf subject.

The profoundly deaf subject* was taken into the studio where he was given an orientation to the experiment, and was also given an opportunity to become acquainted with the personnel and the equipment. He was then shown the vowel [ɑ] (a(r)) which was printed on a 5 x 7 card and was asked to watch the visual display as the teacher produced a single-pitch vowel with prolonged duration. The subject would then attempt to imitate the teacher's visual display by producing the same vowel. This procedure was followed with the following vowels: [ɑ] (a(r)), [oU] (o-e), [i] (ēē), [ɛ] (e), [u] (o͞o), [mi] (mēē).

E. Instructional lesson 1:

Because of the need for some evaluation by means of listening tests, it was necessary to perform pre-instructional and post-instructional testing. The pre-instructional testing procedure, performed at the start of the first session, consisted of the following: each subject was taken individually into the listening studio; the therapist showed each subject the flash card that contained the vowel to be tested. Each vowel was first presented in a sustained, single pitch in order to establish the concept of imitating the teacher's visual display. Each vowel was presented using first upward inflection followed by downward inflection. The Northampton Vowel Chart was used for the following vowels: [ɑ] (a(r)), [oU] (o-e), [e] (a-e), [u] (o͞o), [i] (ee), and [ɛ] (e). Then the subject was asked to watch the therapist produce a visual display. When the therapist had finished producing the visual display of the vowel, the child was instructed to produce the same vowel sound in an attempt to imitate the therapist's visual display. There was no additional instruction. This procedure was followed for each vowel sound. The entire pre-instruction experiment was tape recorded.

F. Instructional lesson 2:

The three subjects were brought into the studio. While one child was being taught, the remaining two children sat near the pitch extractor and observed the teacher and the subject. Each subject was given stimuli for and responded to the entire vowel sequence before another subject was taught. The material used during this lesson was identical with the material used during lesson 1. However, this time three successive stimuli were presented by the therapist. At times this procedure varied in accordance with individual differences of success or failure of the subject to imitate the therapist's visual display. During this lesson kinesthetic clues were introduced for the first time. Each child placed her hand in the area of the therapist's pharynx and larynx and her own pharynx and larynx during the production of each vowel sound. Finally, the notions of diaphragmatic breathing and better sitting posture were introduced.

G. Pre-instructional training.

Following the preceding lesson, two days later, the therapist visited the Boston School for the Deaf for the purpose of conducting pre-instructional training with

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* See Appendix B.

the children using the VU meter and a tape recorder. Each child was given instruction in better volume control and duration of production.

Prior to the third instructional lesson, pre-instruction volume training was conducted with each child in the studio at Northeastern University. Using the VU meter, each subject was seen individually and asked to sustain the production of each of six vowel sounds. From these six, the three vowels which were more easily produced by each subject were selected for further duration and volume control training.

H. Instructional lesson 3:

This lesson was carried out in the same manner as the previous two lessons with the following exceptions: (a) each child was seen individually in the studio while the other two subjects waited outside in the control room with the engineer, (b) only three vowels, [ɑ] (a(r)), [oU] (o-e), and [u] (o͞o), were used with two of the subjects, and only two vowels [ɑ] (a(r)) and [oU] (o-e) with one of the subjects, (c) the sequence of presentation was altered from downward-to-upward inflectional pattern to upward-to-downward inflectional pattern.

I. Instructional lesson 4:

The instructional procedure for this lesson was the same as in the previous lesson.

VI. EXPERIMENTAL DATA AND FINDINGS

During the pre-instructional sessions and the instructional lessons themselves, many observations were made. The basic data consisted of pitch pattern curves as they appeared on the screen of the pitch extractor*. The following observations were also made:

(a) The concept of pitch variation which is not understood by profoundly deaf individuals seemed to be understood by the three children as manifested by their attempts to imitate the teacher's pitch pattern curves.

(b) The pitch extractor equipment appeared to serve as an excellent stimulator for verbalization by the subjects.

(c) There appeared to be different degrees of imitation with different vowels.

(d) Pleasant interpersonal relationships were observed.

(e) Certain variables that significantly influence success or failure of the learning and teaching process were gleaned from the observation of the process.

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* See Appendix G for oscillograms of the various curves obtained during each instructional lesson.

VII. ANALYSES OF THE DATA AND FINDINGS

A. Subject A

1. Instructional lesson 1: (See Appendix C) This child had an extremely harsh voice quality and used high thoraic breathing. These two factors seemed to cause her to vocalize with residual breath. Consequently, she experienced weak breath support. Because of this it was necessary to help Subject A to achieve deeper breathing and improved breath support. Although very little improvement was noted immediately after breathing exercises, more progress was observed toward the conclusion of the session when she realized that the upward and downward changes in the pitch patterns seen on the visual display scope were caused by changes occurring in her larynx.

When this subject became aware of the relationships between physiological and visual display changes, she became excited and seemed intrinsically motivated to continue her attempts at imitating the teacher's pitch patterns. Also, she displayed eagerness in showing the other two subjects how to perform the task.

2. Instructional lesson 2: This subject continued to show an eagerness to participate. She was constantly using non-verbal means to communicate with her two friends that she understood what to do; consequently, she attempted to help the other subjects to learn how to do it. Because of this distraction and other similar distractions during the lesson, it was decided to change the procedure during the next lesson so that only the child being tested would be permitted in the studio; the remaining two subjects would wait outside in the control room.

This child seemed to grasp the concept of pitch variation. She seemed determined to match the teacher's pitch shift. However, she performed well at the beginning of the lesson and poorly toward the conclusion of it. The pitch extractor and its various buttons and gadgets appeared to attract her more than the teacher's instructions.

It was also noticed during this session that this subject would lower her mandible, thus modifying the articulators and changing the vowel, when attempting to imitate downward pitch inflections. It was noticed that the vowels [ɑ] (a(r)), [oU] (o-e) and [u] (o͞o), were easier for this subject to imitate than the other vowels; therefore, it was decided during the following lessons the number of vowels used would be limited to those which she can produce and imitate best. In addition, it was learned that she could imitate an upward-to-downward pitch change easier than she could a downward-to-upward shift; therefore, during the following lesson, the stimuli were given in the easier order.

Volume and duration or the sustaining of the vowel sound are crucial factors in determing the subject's ability to imitate pitch patterns provided on the visual display by the therapist. Because of this, it was decided to provide some pre-instruction volume control and duration exercises. Improved breath support and better ability to sustain the vowel sound resulted in improved imitative pitch patterns on the visual display scope.

3. Instructional lesson 3: This child definitely understood what she was supposed to do during the lesson. When she was asked to imitate the single pitch (flat) curve she was slightly higher than the therapist's curve; however, the second attempt

was a closer approximation while the third attempt was a closer approximation than the second one.

During the upward-to-downward pitch variation attempt by the subject, she did not accurately match the teacher's pattern, but she approximated the general upward-to-downward movement of the pattern with each of the three vowels. With the vowels [oU] (o-e) and [u] (oo) she continued to lower the mandible to obtain a downward shift pattern on the screen. This obviously distorted the vowel.

An interesting observation of this child is that she has the highest intelligence quotient of the three girls and also has the highest grade placement average of the three subjects. In this pilot study, she learned the concept of pitch inflection faster than the other children. The importance of intelligence was also demonstrated during the trial session with the 17 year 10 month old high school sophomore. He was an intelligent profoundly deaf young man (103 WAIS) who grasped the concept very quickly. Therefore, it might be safe to say that one of the most important variables in the teaching and learning process was intelligence.

4. Instructional lesson 4: The fourth and final lesson took place following the post-instructional procedures which will be discussed later. The teaching procedure for this lesson was the same as in the previous lessons. Subject A appeared highly motivated and determined to do well; however, there was evidence of a noticeably limited attention span for her as compared to the other subjects. This girl manifested considerable diffuse anxiety and was very easily distracted. Nevertheless she did approximate the upward or downward inflections of the therapist's pattern several times.

B. Subject B

1. Instructional lesson 1: (See Appendix E) Of the three subjects, this subject's voice seemed to have the most satisfactory vocal quality. In the beginning, subject B exhibited fair imitative ability. There were discernible visual and auditory differences. On the other hand, it was felt that the differences were caused by the trial-and-error method used by the subject; it was not understood to be a product of concept understanding. Toward the conclusion of the lesson, subject B became noticeably fatigued and her performance diminished.

2. Instructional lesson 2: This subject appeared eager to please the therapist and was relaxed during the entire session. Using kinesthetic clues, this subject performed more effectively than the other subjects. She revealed better ability to imitate in the initial phase of her attempts than in the final one. This seemed to be due to insufficient breath support which is needed in order to sustain the curve. At times this subject indicated that she could "feel" differences produced during upward and downward inflections.

3. Instructional lesson 3: This subject showed enough imitative ability during this session to indicate a definite understanding of the concept of pitch variation. Her motivation was obviously high and determined efforts were made to imitate the therapist's pitch curve as seen on the visual oscillographic display. The pitch inflection variation was reversed to high-to-low because it was felt that this shift was more easily made by the subject.

4. Instructional lesson 4: During this lesson, subject B imitated the therapist's pattern most consistently. She indicated that she understood the concept of pitch inflection and produced an imitative pattern when instructed. Kinesthetic stimuli helped subject B to imitate the patterns.

It was interesting to note that B's pitch range and vocal quality were more similar to those of the therapist. This observation seemed to warrant the imperative consideration of the similarities between the subject's and the therapist's pitch range and vocal quality in determining the ability to imitate pitch inflection patterns with the help of visual means.

Extreme improvement was noted in B's performance during this final session. Her imitative abilities are illustrated in Appendix G.

C. Subject C

1. Instructional lesson 1: (See Appendix E) This subject is a physiologically thin child with a relatively small frame. She has an extremely high-pitched voice, and, generally, insufficient volume. Improved breathing resulted in a clearer, more imitative pitch pattern on the oscillographic display. A pleasant, shy child, she seemed to thoroughly enjoy the equipment. She was motivated to participate and to learn. She tried very, very hard. She was taught with and without kinesthetic clues and performed better with the clues than without them.

With this subject it was felt that any observable change in pitch pattern curves was due to a change in volume or due to vocal fading rather than a true pitch variation. She could imitate the vowels [oU] (o-e) and [ɑ] (a(r)) best. When producing the vowel [i] (ēē), she would move her entire body upward which seemed to indicate that she realized that she should cause the visual pattern to move in the direction of up, thus effecting an imitation of the therapist's pattern.

2. Instructional lesson 2: The question of physiological structure and its significance in relation to this subject's inability to imitate the teacher's pitch arose again during this lesson. Her pitch is quite high and tense vocal quality is obvious. Although this subject did reveal slight improvement during this lesson, the therapist and the pathologist felt that the concept of pitch variation was not truly understood; rather, vocal fading produced a change in oscillographic display.

3. Instructional lesson 3: The lesson for this subject was aborted because of equipment problems which could not be solved immediately; therefore, this subject's lesson had to be terminated before she had an opportunity to attempt to imitate the entire vowel series. As was pointed out earlier, this girl had extreme harshness and breathiness as well as a very high-pitched voice, and these factors showed up in the pitch scope display more so than ordinarily; thus the errors in the displayed pitch pattern might have been caused more by the technical malfunctions than by the inability of the subject to produce a correct pattern.

4. Instructional lesson 4: Because of the amount of time that was needed for the post-instructional procedures, there was a minimum amount of time remaining for this subject. Nevertheless,for the little time that was devoted to this girl, it was observed that her performances were not as good as the performances by the other two subjects. This seemed to be a consistent trend throughout the lessons of the pilot study.

D. Post-instructional testing.

Each of the three subjects was seen in the identical order for post-instructional testing as they were seen for the pre-instructional testing.* To insure consistency of procedures, the order of inflection pattern presentation was likewise maintained: sustained, single-pitch signal, upward pitch-shift inflection, downward pitch-shift inflection. Each subject was brought into the testing studio individually and received no instruction other than: "Please watch me. I'll do it first, then you do what I do". The teacher then provided the pitch patterns by means of his voice and the subject tried to imitate.

The post-instructional testing was complicated by certain malfunctions of the equipment which tended to concern and confuse the subjects. Adequate volume was a crucial problem in that each subject had to be close to the microphone for a sufficiently large input signal, but at the same time could not be extremely close because breathiness picked up by the microphone would cause errors in the display. As a result, a good many of the pitch patterns produced by the subjects were complex and unreadable.

E. Comparison of pre-instructional and post-instructional imitations.

In order to compare the degree of success in pre-instructional imitation to the post-instructional imitation success, a listening test composed of both pre-instructional and post-instructional stimuli, as produced by the subjects, was prepared and presented to a panel of six expert judges. The judges were faculty members and graduate students who were not involved in this project. The listening test was held in the same studio where the instructional lessons took place. The judges were instructed to rate the subjects' degree of imitation of inflection, using the rating sheet presented in Appendix H.

Each utterance of the subjects was preceded by the corresponding utterance of the teacher. Although the pre-test recording of all tested vowels for each subject was kept in a group and similarly also for the post-tests, these groups were presented to the judges in a randomized order as indicated in the following list:

a. Subject A, pre-test.
b. Subject B, post-test.
c. Subject C, post-test.
d. Subject A, post-test.
e. Subject B, pre-test.
f. Subject C, pre-test.

According to the rating scale**, a better imitative achievement is indicated by a lower number. The cumulative rating of the seven judges, for the three subjects A, B, C, for an upward inflection imitation as well as for a downward inflection imitation are given in Figs. 5 through 7.

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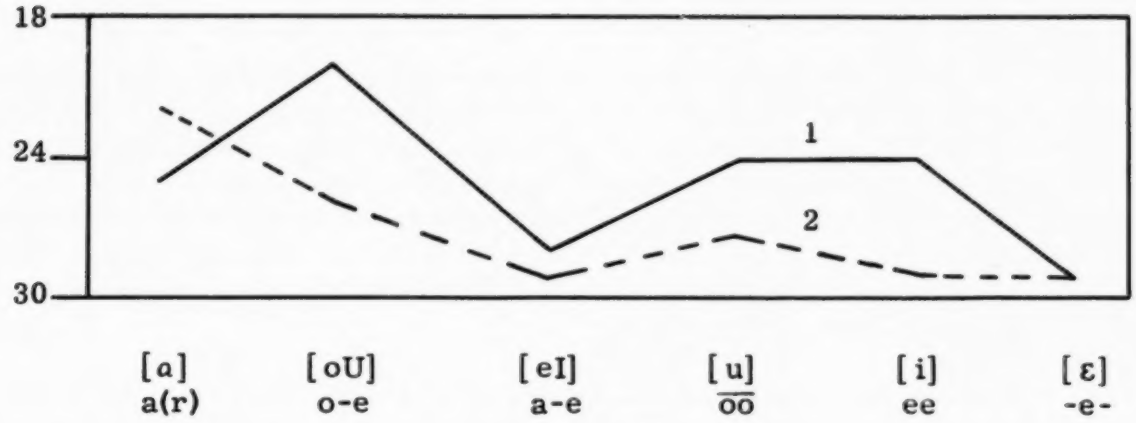
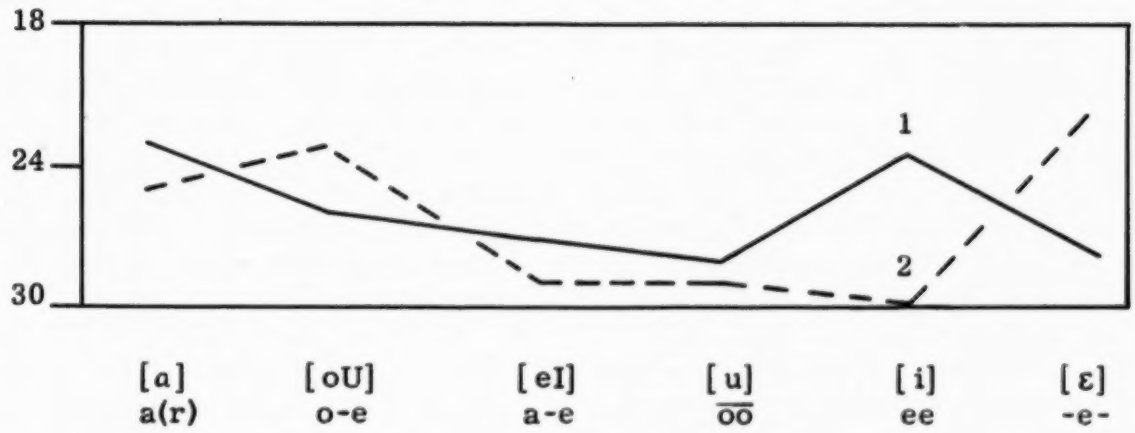
* See Sec. VE

** See Appendix I



a. upward inflection



b. downward inflection

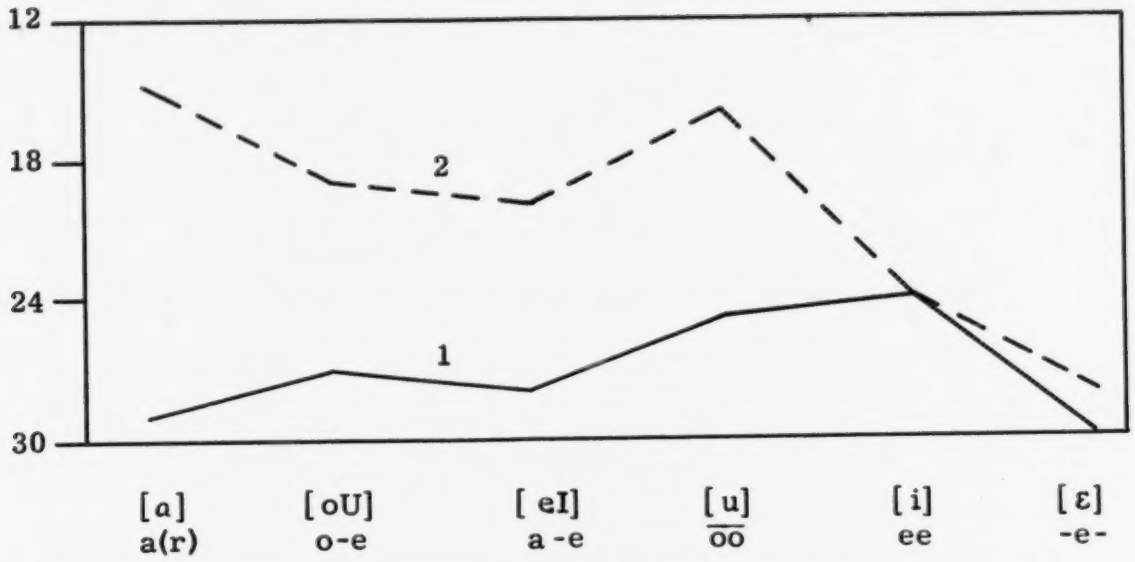
Fig. 5. Subject A; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.

VIII. CONCLUSIONS AND IMPLICATIONS

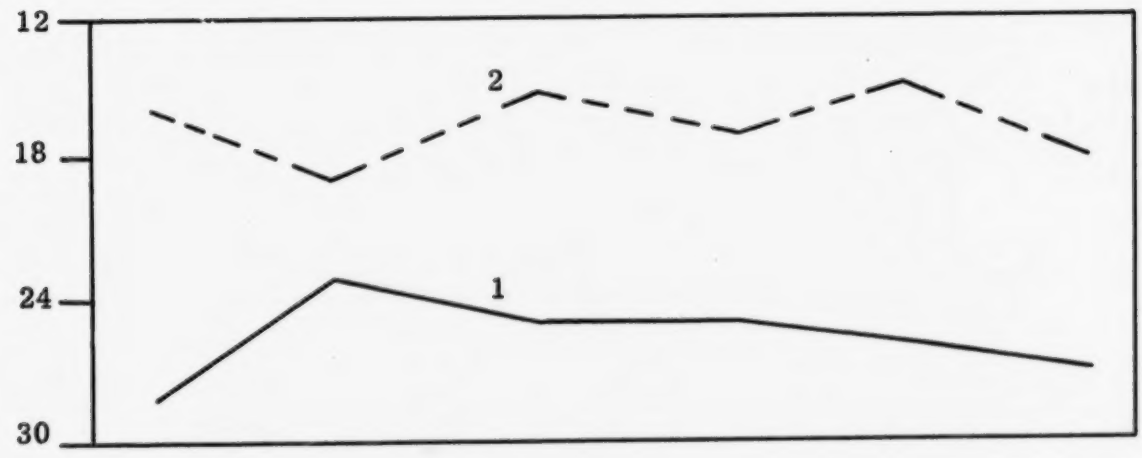
Based on the observations made during this pilot study, it is felt that the following statements may be made:

1. The concept of teaching pitch variation or pitch inflection to deaf individuals using a self-monitoring device such as the pitch extractor is possible.

2. Volume and duration were most significant factors in the production of the visual display; therefore, pre-instructional exercises in volume increase and control were necessary.



a. upward inflection



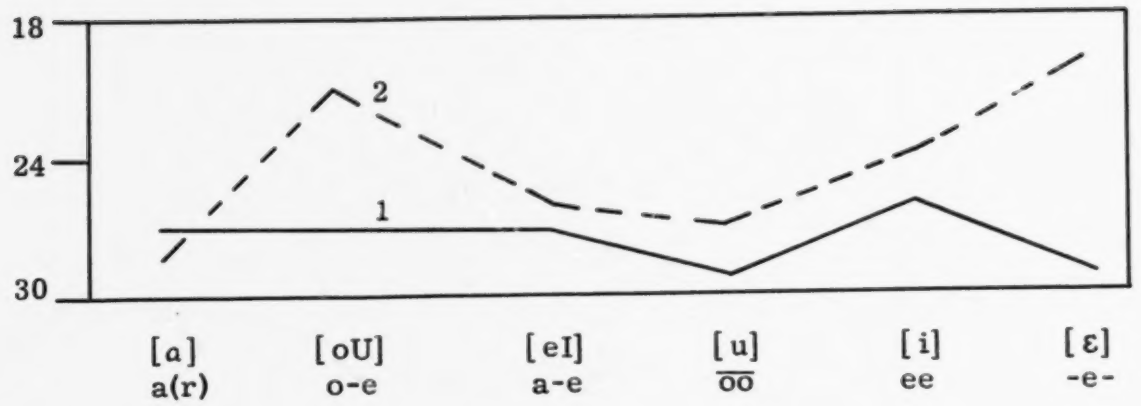
b. downward inflection

Fig. 6. Subject B; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.

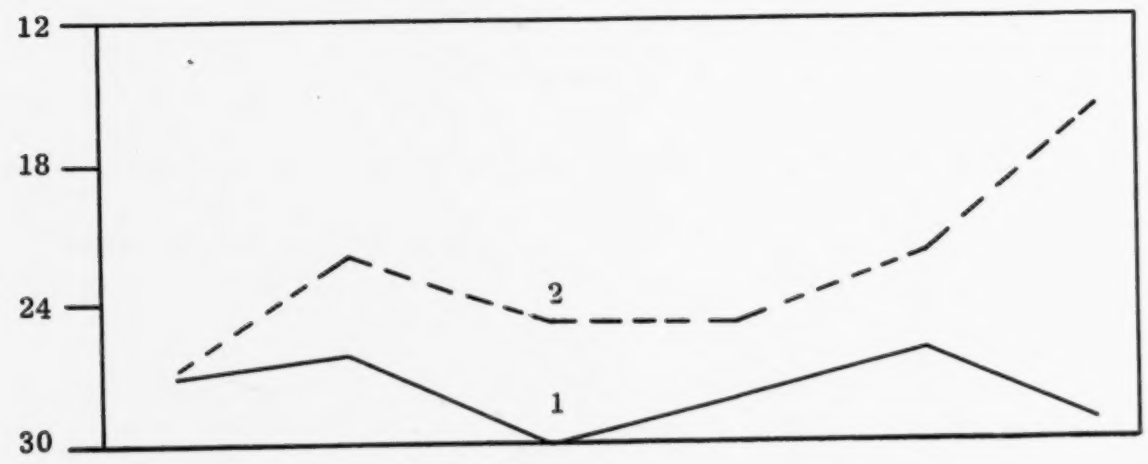
3. Change in volume (particularly vocal fading at the end of the display) was sometimes visually perceived as a change in pitch; i.e. a reduction in volume of the subject's voice was accompanied by a gradual downward shift in pitch frequency.

4. Intelligence of the subject appears important for successful performance.

5. Physiological structure of the subject and level of anxiety, hyperactivity, and distractibility are significant factors, related to performance in a negative way.



a. upward inflection



b. downward inflection

Fig. 7. Subject C; cumulative pre-instruction (1) and post-instruction (2) scores for various vowels, as rated by six judges.

6. Similarity of the subject's and the therapist's voice quality and pitch range appear to be important variables in determining the ability to imitate the visual display pattern.

7. Attention and interest spans are two additional important variables to be considered in the teaching and learning process. Twenty-minute instructional lessons are about the maximum which young deaf children can endure in this kind of activity.

8. Each subject should be taught the series of vowels individually without observers, i.e. other subjects in the room.

9. Lessons should commence promptly; otherwise children become too involved with the machine and its gadgets. Transition from this sort of involvement to the rigors of the teaching and learning process is difficult.

10. Upward-to-downward pitch inflections should be presented first because they can be more easily imitated.

11. All available additional stimuli should be used as aids in teaching.

12. Three successive stimuli are most effective. Three appeared to be sufficient, and time saving as well.

13. Peripheral, background noises within the studio and building interfered with the clearness of the oscillographic display.

14. The pitch extractor served also as a stimulator for subject verbalization.

15. A small desk lamp was needed in the studio because the diffuse overhead illumination interfered with the clarity of the oscilloscopic display.

16. Constant cooperation and coordination between technical and non-technical staff members was imperative.

IX. LIMITATIONS

The conclusions and implications stated in this report should be read with the following limitations in mind:

1. The number of instructional lessons was limited to four. A much larger number would be desirable.

2. Imperfect functioning of the pitch extractor often interfered with the teaching and learning process, inasmuch as distorted pitch patterns displayed on the scope confused the subjects.

X. SUGGESTIONS FOR FURTHER RESEARCH

It is recommended that the following suggestions be considered for further research:

1. Extension of the present study with respect to an increase in the number of instructional lessons.

2. Comparative study of inflection instruction with matched groups of normal-hearing and profoundly-deaf children.

3. Extension of the present study with a group of profoundly deaf young adults with above-average IQ.

4. Study of more reliable pitch-extraction methods, including throat-microphone pickup.

5. Investigation of improved visual display methods, including trace-suppression for unvoiced sounds and silent intervals, etc.

6. Study of techniques to minimize the visual effect of pitch-extractor errors which confuse the subject.

XI. REFERENCES

1. Anderson, F., "An Experimental Pitch Indicator for Training Deaf Scholars," J. Acous. Soc. Amer., Vol. 32, No. 8, pp. 1065-1074, August, 1960.

2. Dolanský, L., "An Instantaneous Pitch-Period Indicator," J. Acous. Soc. Amer., Vol. 27, No. 1, pp. 67-72, 1955.

3. Dolanský, L.O., "Studio for Listening Tests," J. Acous. Soc. Amer., Vol. 33, pp. 175-181, March 1958.

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5. Kopp, H., "Visible Speech," Ibid., Vol. 50, 1948, p. 61.

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9. Sugimoto, T. and Hiki, S., "On the Extraction of the Pitch Signal Using the Body Wall Vibration at the Throat of the Talker," Paper C10, Proc. Speech Communication Seminar, Vol. I, Stockholm, 1963.

10. Tjernlund, P., "Aids for the Deaf," Quarterly Progress and Status Report, Speech Transmission Laboratory, Royal Institute of Technology, Stockholm 70, Sweden, October 15, 1964.

APPENDIX A

PITCH-EXTRACTION EQUIPMENT AND LISTENING FACILITIES

1. Introduction.

The main purpose of this appendix is to describe the electronic equipment which was used to obtain the display of pitch frequency vs. time, and also to give certain information about the listening facilities which were used for the instruction of the deaf subjects as well as for the listening tests performed by a group of expert judges.

2. Pitch-extraction and display equipment.

As indicated in the main body of the report, the pitch-display method used in this research was based on the pitch-period indicator described earlier in the literature[2]. Certain modifications and additions had to be made, however, before the available equipment could be successfully used for the present purpose. These changes and additions will be described in Sec. 3. The overall scheme used and the function of its various parts are best understood by means of Figs. A1 and A2. In Fig. A1, various important waveforms are shown with respect to a common time scale. The waveform-identifying letters a, b, etc. will also be found in Fig. A2, thus identifying the various points at which the waveforms occur. The signal chosen to demonstrate the operation of the setup is the word "choice". The microphone input signal is represented as (a) while (b) represents the triangular signal derived from it. While the height of the top point of each triangular portion is proportional to the spacing T, the quantity of interest is the fundamental frequency of the voice $f_p \sim 1/T$. Therefore, subsequent to an inversion and peak detection (c), a divider is used to perform the desired conversion $f_p \sim 1/T$, (d). The inversion which has been just mentioned is necessary in order to obtain the polarity required by the divider.

Thus far no provision has been made to eliminate unwanted parts of the waveform (d), which correspond to either silence or unvoiced speech sounds. In order to eliminate such undesired parts in the display, a voiced-unvoiced indicator is used to identify such undesired portions; with the help of a gate using the information in the control waveform (e), the undesired portions of the divider output (d) may be eliminated from the visual display. The remainder of the pitch-vs.-time curve (f) then appears on the face of the oscilloscope and may be stored there for long periods of time, if desired.

3. Equipment modifications and additions.

Referring to Fig. A2, it is seen that the microphone signal obtained by means of the Altec 633A microphone is amplified in the PT6-J Magnecorder amplifier and then fed to three Krohn-Hite filters (a). The upper filter (360-A) is a rejection filter with the rejection band set for the range .6kHz to 200kHz. It is used in the pitch-signal extraction branch preceding the pitch-period indicator, in order to eliminate certain high frequencies.

a. Pitch-period indicator: A detailed description of the pitch-period indicator is given in ref. 2. The circuit diagram for this unit is presented as Fig. 5 of the same reference.

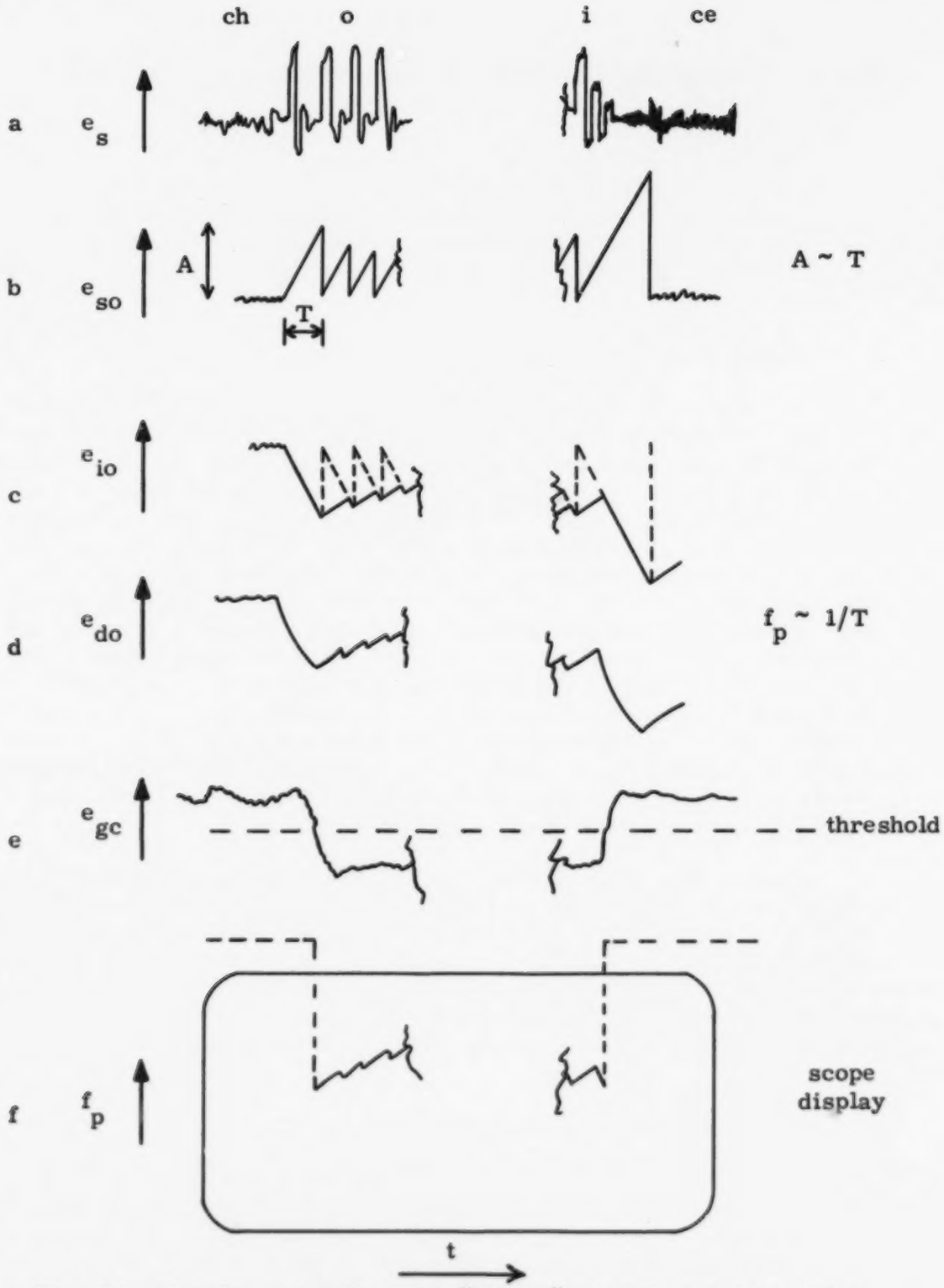


Fig. A1. Waveforms for the word "choice" at various points of the pitch extracting equipment, (a) speech-signal input e_s, (b) saw-tooth generator output e_{so}, (c) detector output e_{io}, (d) divider output e_{do}, (e) gate control signal e_{gc}, (f) pitch frequency (f_p) vs. time (t) display on oscilloscope. (Time scale expanded with respect to normal use.)

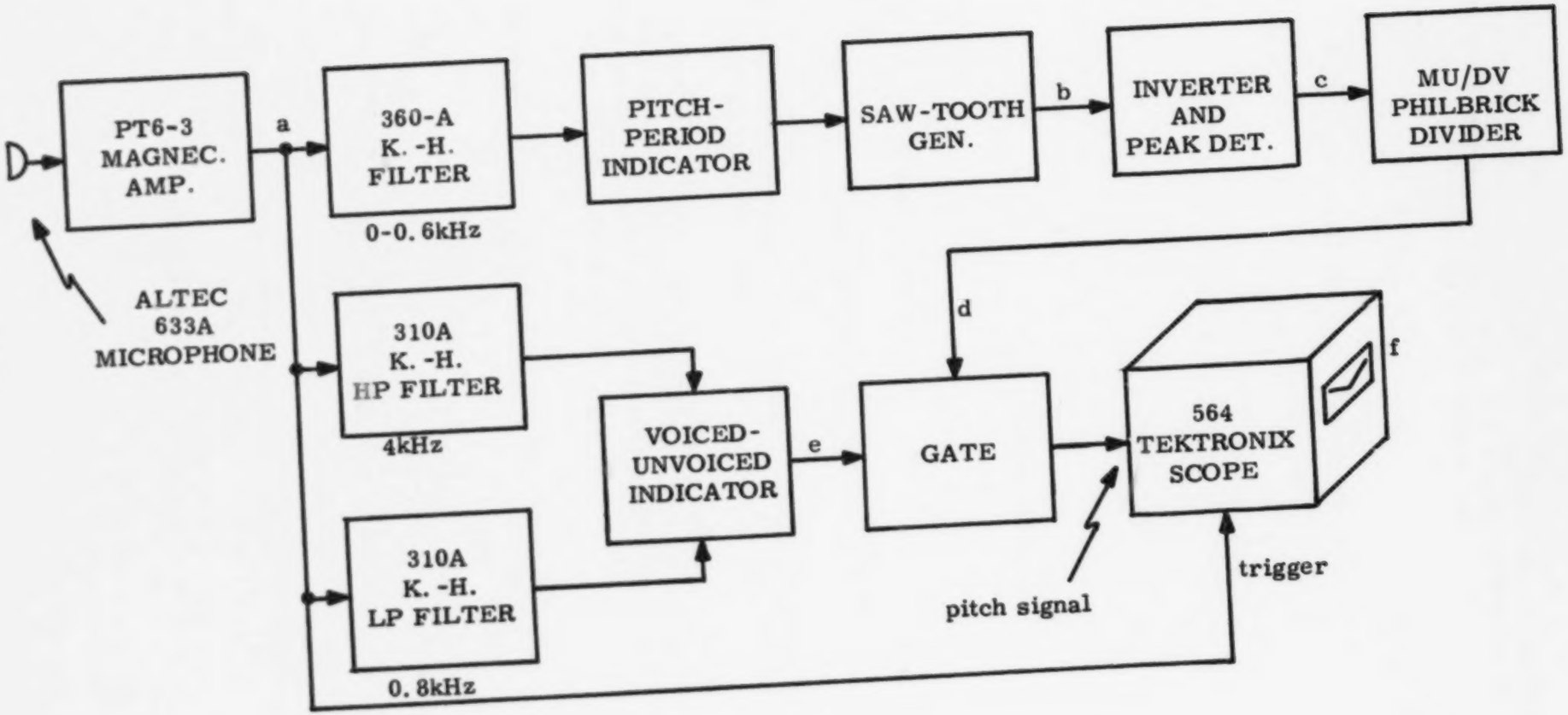
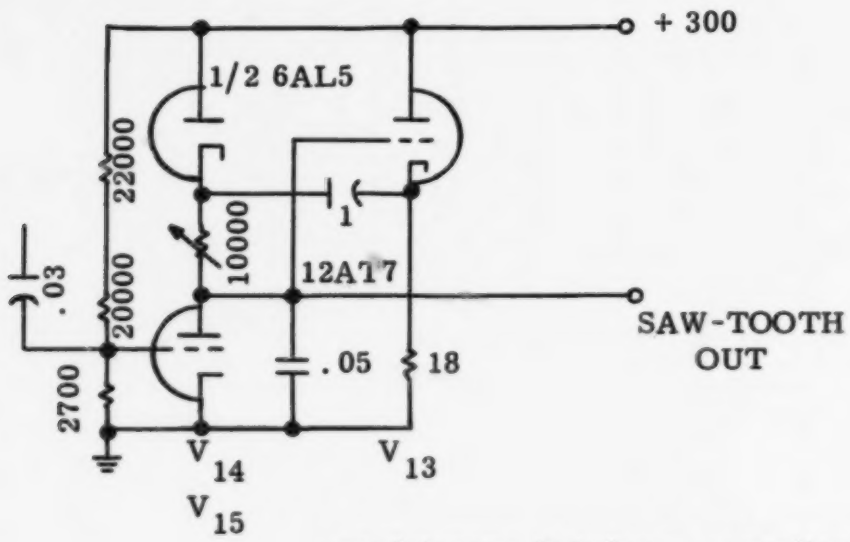


Fig. A2. Pitch-extractor and display equipment. The waveforms at the points identified by the letters a, b, c, etc. are shown in Fig. A1.

b. Saw-tooth generator. The saw-tooth generator which follows the pitch-period generator represents a modified version of an output blocking circuit*. In this modification the stages V13, V14 and V15 have been replaced by the circuit given in Fig. A3, while the stages V7 through V12 of the original blocking circuit are

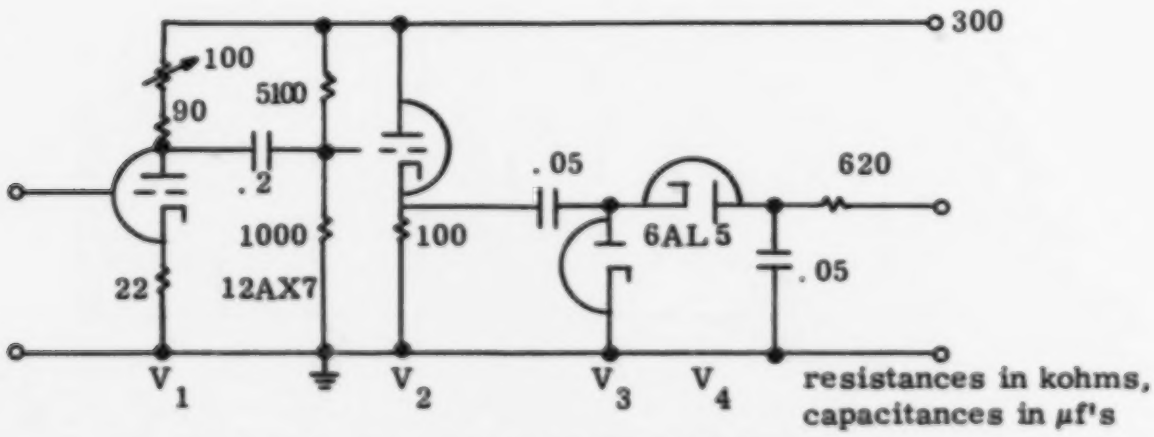


resistances in kohms, capacitances in μf's

Fig. A3. Saw-tooth generator

not used. The result of this modification is that instead of the originally generated triangular waveform (see Fig. 3b), a triangular waveform (b) is obtained, as desired.

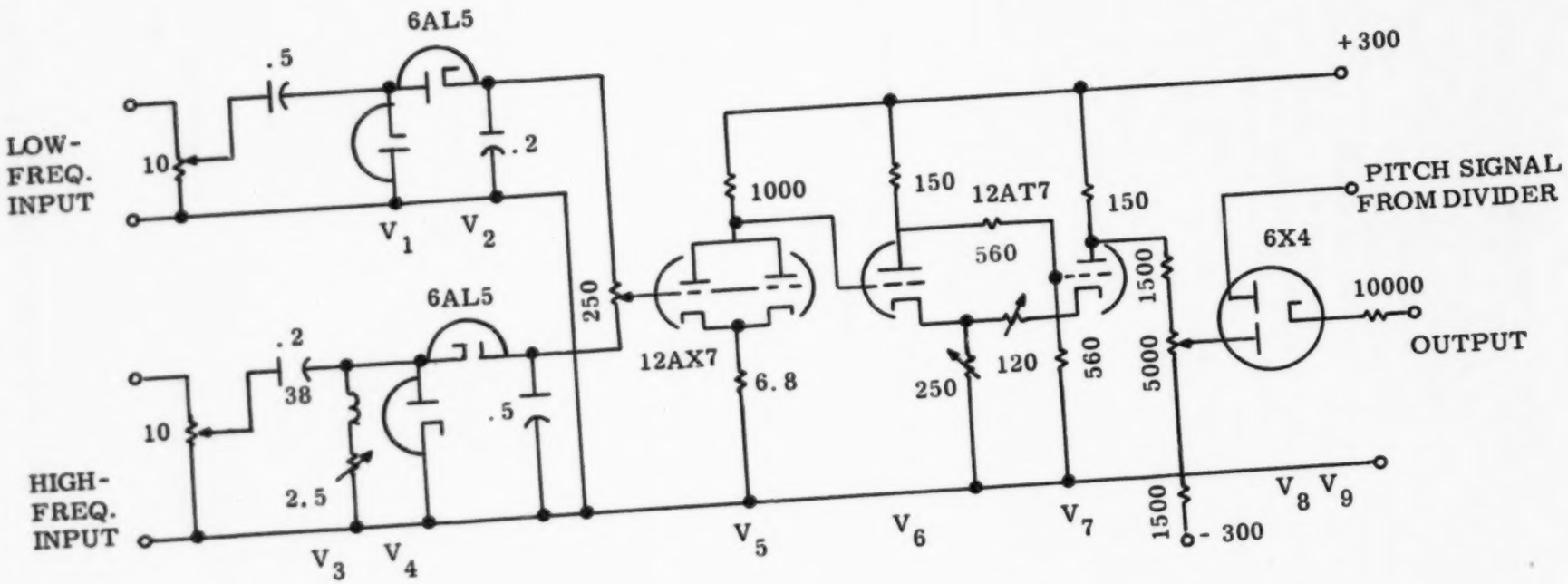
c. Inverter and peak detector. In order to obtain a signal of the proper polarity for the input of the Philbrick divider, a signal inversion is obtained in V1, Fig. A4. A peak detection which is also desired in order to see clearly the peaks of the triangular waveform, is then performed in stages V3 and V4.



resistances in kohms, capacitances in μf's

Fig. A4. Inverter and peak detector.

* Fig. 6, ref. 2.



resistances in kohms, capacitances in μf's

Fig. A5. Voiced-unvoiced indicator and gating circuit.

d. Divider. The resulting waveform (c) must now be used to divide a constant in order to obtain a display in terms of pitch frequency rather than pitch-period time spacing. This is accomplished by a commercially available divider, Philbrick MU/DV. The signal (d) is now ready for the display except for certain extraneous parts of the trace which correspond to either silence or unvoiced speech sounds. To eliminate these latter portions, a voiced-unvoiced indicator and gating circuit are used (Fig. A5). The control signal (e) for the gate is obtained by means of a voiced-unvoiced indicator. In essence two signals, one derived from the frequency band above 4 kHz, the other from the frequency band below 0.8 kHz are obtained and subtracted. In Fig. A5, the low-frequency input is peak-detected in V1, V2, while the high-frequency input is detected with the opposite polarity in V3, V4. The two signals are then algebraically added, amplified (V5) and the amplified signal used to activate a Schmitt trigger circuit (V6, V7). The output of V7 is then used to shift the electronic beam outside of the viewing field when a voice signal is not present. This is accomplished in V8, V9 in which a large positive signal is fed to the output when a voiced input is not present. Otherwise, the pitch signal from the divider (d) appears on the screen (f). It would be more desirable to suppress the beam by means of Z-modulation instead of shifting the beam outside of the field of display. However, this was found for the time being difficult to achieve because of certain peculiarities with respect to the method of obtaining the bias for the display tube.

e. Visual display. For the visual display, a Tektronix 564 oscilloscope was used. The latter can be operated in a storage mode so that the pitch-signal pattern produced by the teacher can be retained on the scope face while several successive trials are attempted by the student.

4. Equipment performance.

The overall behavior of the pitch-extraction and display equipment represented in Fig. A2 is reflected in Fig. A6. In this diagram the vertical deflection

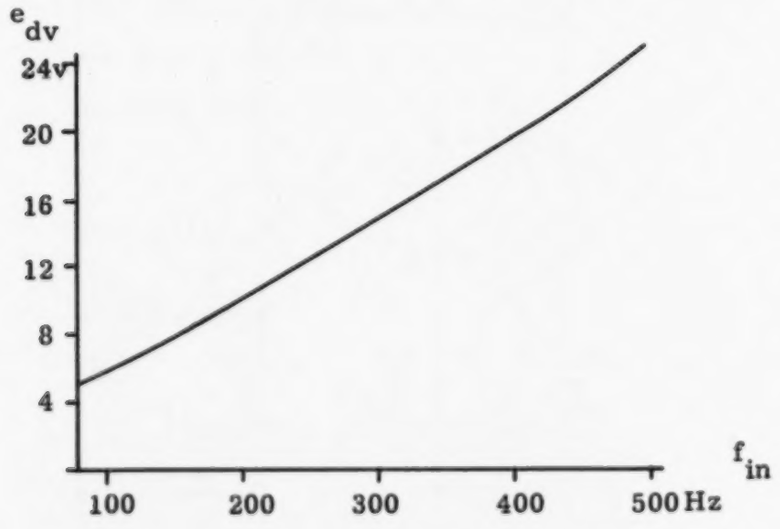
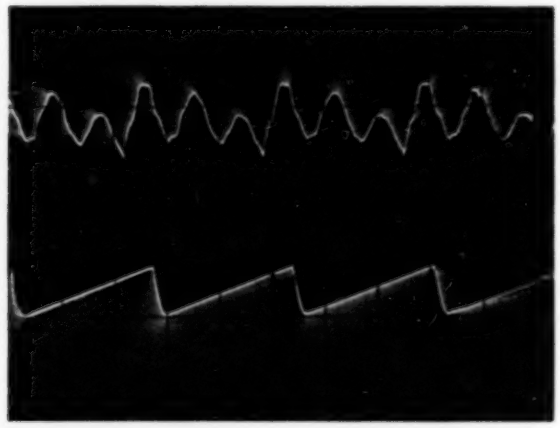


Fig. A6. Vertical deflection voltage e_{dv} vs. pitch frequency f_{in}.

on the scope face is given as a function of the input frequency, for a sinusoidal input. Oscillograms of waveforms a, b, e and f (corresponding to the waveforms sketched in Fig. A1) are given in Fig. A7.

(1)

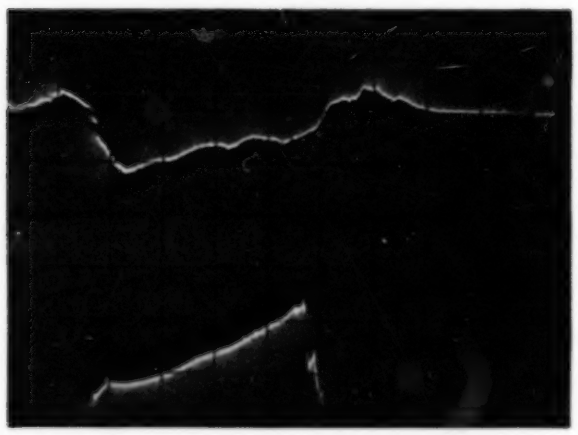
(2)



A. (1) Input signal e_s (at point a) for vowel [e] (a-e),
(2) Corresponding saw-tooth waveform e_{so} at b.

(1)

(2)



B. (1) Gate control signal e_{gc} for the word "choice" (at point e);
(2) Corresponding visual display pattern f.

Fig. A7. Examples of waveforms obtained at points a, b, e, f (See Fig. A1 and A2) in actual operation.

5. Listening room.

Instruction and testing of the deaf subjects, as well as the final tests in which pre-instructional and post- instructional recordings of the subjects' responses were presented to a group of expert judges, were performed in the listening studio described earlier in ref. 3. The 633A microphone (see Fig. A2) was located on a table between the teacher, the student and the oscilloscope used for display.

6. Concluding remarks.

As indicated in Sec. VIII, the experience with the development and use of this pitch-extraction and display equipment showed definite promise in its use as a tool for teaching pitch variation and inflection to the deaf. However, time did not permit to include in the equipment many desirable features which became evident in the process. Among those to be recommended in future work of this kind are the following:

a. A logarithmic conversion of the vertical scale of the final pitch display appears desirable, particularly if large differences in pitch are to be accommodated (e.g. male vs. children's voice). In the present equipment the vertical deflection is approximately linearly related to the frequency (See Fig. A6).

b. Automatic diode biasing in the pitch-period indicator (e.g. ref. 2, Fig. 5, stage V11) as suggested by Anderson[1] should result in fewer erroneous indications generated by the equipment.

c. An insertion of a box-car circuit after the saw-tooth generator would prevent an occasional error to be emphasized out of proportion. Such an arrangement would keep the just preceding indication constant rather than erroneously indicating half the correct frequency.

d. A further reduction of pitch-indicator errors could be achieved by the use of a throat microphone which gives a much simpler input waveform and also gives a signal which varies in magnitude much less than the normal microphone signal.

e. The incorporation of automatic volume control at the input would further reduce the dynamic range over which the equipment must operate reliably.

f. With the incorporation of the above-mentioned changes, a less elaborate pitch-indicator circuit probably consisting only of two rather than the present six repeated sections would most likely be sufficient.

References

1. Anderson, F., "An Experimental Pitch Indicator for Training Deaf Scholars," J. Acous. Soc. Amer., Vol. 32, No. 8, pp. 1065-1074, August, 1960.

2. Dolanský, L.O., "An Instantaneous Pitch-Period Indicator," J. Acous. Soc. Amer., Vol. 27, No. 1, pp. 67-72 (1955).

3. Dolanský, L., "Studio for Listening Tests," JASA, Vol. 30, No. 3, pp. 175-181, March 1958.

APPENDIX B

SUBJECT DATA SHEET FOR YOUNG ADULT

Full Name of Subject:	Howard Schlang
Address:	619 Morton Street, Mattampan, Massachusetts
Schools Attended:	Pauline A. Shaw Kindergarten Horace Mann School for the Deaf Hyde Park High School
Chronological Age:	17-10
Date of Birth:	1947-11-2
Psychometric Assessment:	Wechsler Adult Intelligence Scale: 103 Administered: 1963-11-27
Standardized Achievement Tests:	American School Achievement (Adv.) Form E, Reading 6.0, Arithmetic 7.9
Audiometric Assessment:	Etiology of Deafness: Bilateral Congenital Nerve Deafness. Wears a Zenith super extended range hearing aid.

APPENDIX C

SUBJECT DATA SHEET FOR SUBJECT A

Full Name of Subject:	Cynthia Jane Taylor
Address:	8 Linebrook Road, Ipswich, Massachusetts
School Attended:	Boston School for the Deaf
Chronological Age:	11-6
Date of Birth:	1954-12-22
Psychometric Assessment:	Wechsler Intelligence Scale for Children
	Performance Tests: 110
	Adminstered: 1963-1-24
Standardized Achievement Tests:	Scholastic Tests Diagnostic Reading.
	Grade 3 Average 80.
Audiometric Assessment:	Etiology of Deafness: Bilateral congential.

APPENDIX D

SUBJECT DATA SHEET FOR SUBJECT B

Full Name of Subject:	**Francine Jeanne Simoneau**
Address:	**17 Congress Street, Manchester, New Hampshire**
Schools Attended:	**Boston School for the Deaf**
Chronological Age:	**10-0**
Date of Birth:	**1955-7-9**
Psychometric Assessment:	**Goodenough Draw-a-Man Test: 96**
	Administered: 1963-1-11
Standardized Achievement Tests:	**Scholastic Tests, Diagnostic Reading Form A,**
	Grade 3, Average 75
Audiometric Assessment:	**Etiology: Congenital bilateral. Mother and father**
	are deaf.

APPENDIX E

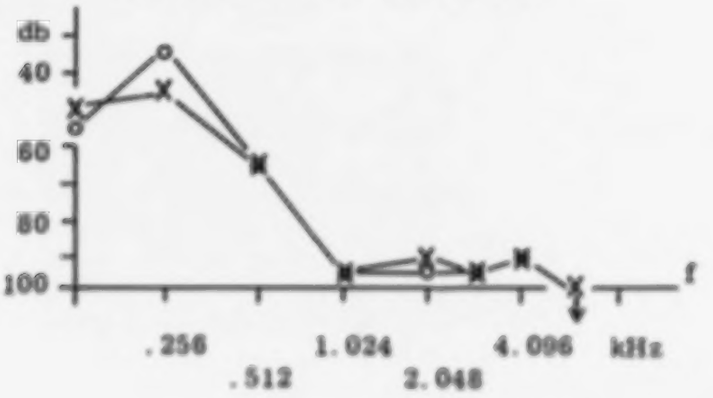
SUBJECT DATA SHEET FOR SUBJECT C

Full Name of Subject:	**Jean Marie Kwiatkowski**
Address:	**330 North Lake Avenue, Worcester, Massachusetts**
Schools Attended:	**Worcester Day School**
	Boston School for the Deaf
Chronological Age:	**11-7**
Date of Birth:	**1953-12-15**
Psychometric Assessment:	**Wechsler Intelligence Scale for Children**
	Performance Scale: 103
	Administered: 1962-2-28
Standardized Achievement Tests:	**Scholastic Tests, Diagnostic Reading Form A,**
	Grade 3, Average 71
Audiometric Assessment:	**Etiology of Deafness: Bilateral Congenital.**

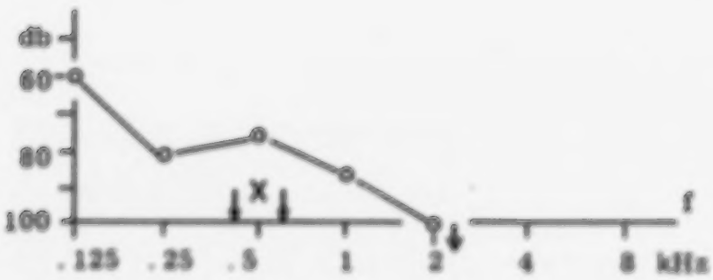
APPENDIX F

HEARING EVALUATIONS OF SUBJECTS

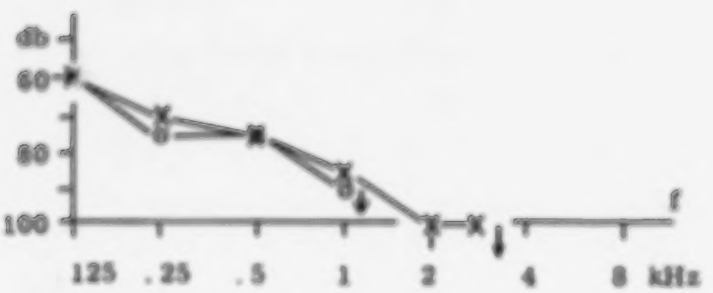
YOUNG ADULT



SUBJECT A



SUBJECT B



SUBJECT C

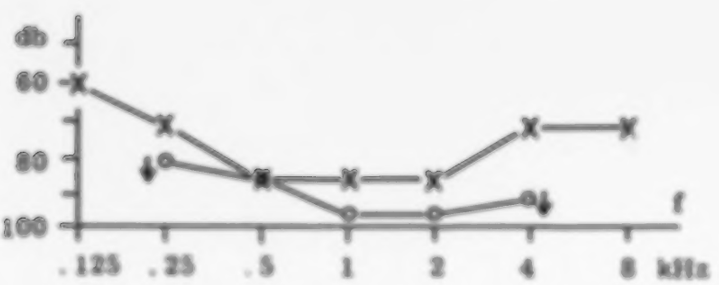
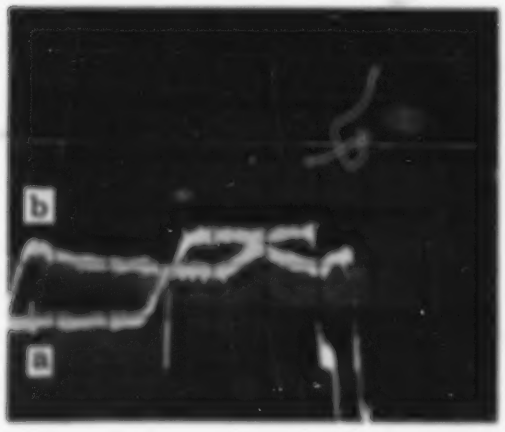
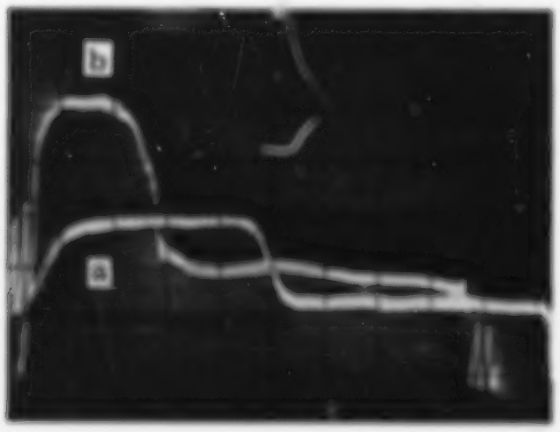


Fig. F1. Audiograms for Deaf Subjects;
o right-ear response, X left-ear response
↓ no response, right ear, ↓ no response, left ear.

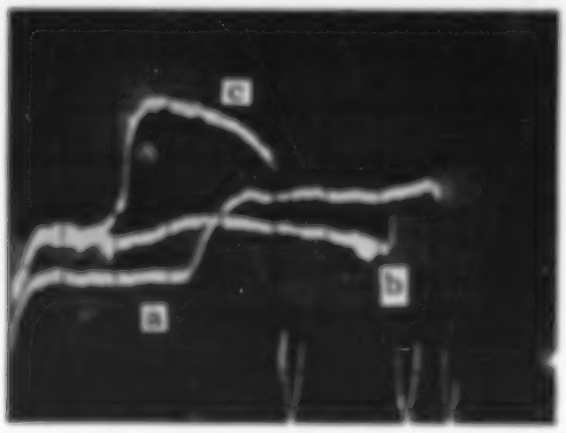
APPENDIX G
OSCILLOGRAPHIC PITCH PATTERNS



a. Pre-instruction response, vowel [u] (oo); (a) teacher, (b) subject



b. Second-lesson response, third trial; vowel [a] (a(r)); (a) teacher, (b) subject



c. Post-instruction response, vowel [u] (oo); (a) teacher, (b) subject, first trial, (c) subject, second trial.

Fig. G1. Examples of pattern-imitation efforts of Subject B.

APPENDIX H

INSTRUCTIONS FOR RATING OF IMITATION

You are about to hear six tape recordings of vowel sounds. The first sound heard will be produced by a teacher with normal hearing. This will be followed by a profoundly deaf child's attempt to imitate the teacher's inflectional (pitch) pattern. Please rate the degree of imitation of inflection using the scale on the record sheet given to you.*

	Most Imitative				Least Imitative
I. Vowels	1	2	3	4	5
[ɑ] a / b					
[oU] a / b					
[o] a / b					
[u] a / b					
[i] a / b					
[ɛ] a / b					
II.	1	2	3	4	5
[ɑ] a / b					
[oU] a / b					
[o] a / b					
[u] a / b					
[i] a / b					
[ɛ] a / b					

* In addition to these written instructions, the judges were told that, in following rating form, (a) relates to an upward inflection, (b) a downward inflection.

III. Vowels	1	2	3	4	5
[a] a/b					
[oU] a/b					
[e] a/b					
[u] a/b					
[i] a/b					
[ɛ] a/b					

IV.	1	2	3	4	5
[a] a/b					
[oU] a/b					
[e] a/b					
[u] a/b					
[i] a/b					
[ɛ] a/b					

V.	1	2	3	4	5
[a] a/b					
[oU] a/b					
[e] a/b					
[u] a/b					
[i] a/b					
[ɛ] a/b					

VI. Vowels		1	2	3	4	5
[ɑ]	a b					
[oU]	a b					
[e]	a b					
[u]	a b					
[i]	a b					
[ɛ]	a b					